# Optical time diffraction as a window into Epsilon Near Zero dynamics

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Nanophotonic time-varying media have recently emerged as thriving field of research, with in particular the rise of Indium Tin Oxide (ITO) as a platform thanks to its strong optical nonlinearities [1]. The unique combination of unity index shifts with femtosecond timescales allows for frequency control of near-infrared and visible light [2]. We demonstrate in a ITO/Au bilayer a temporal analogue of Young's double slit experiment [3] by measuring a diffraction pattern in frequency. We then propose to use the modulated spectrum in a temporal single [4] or double slit experiment as a probe into the nonlinear material dynamics.

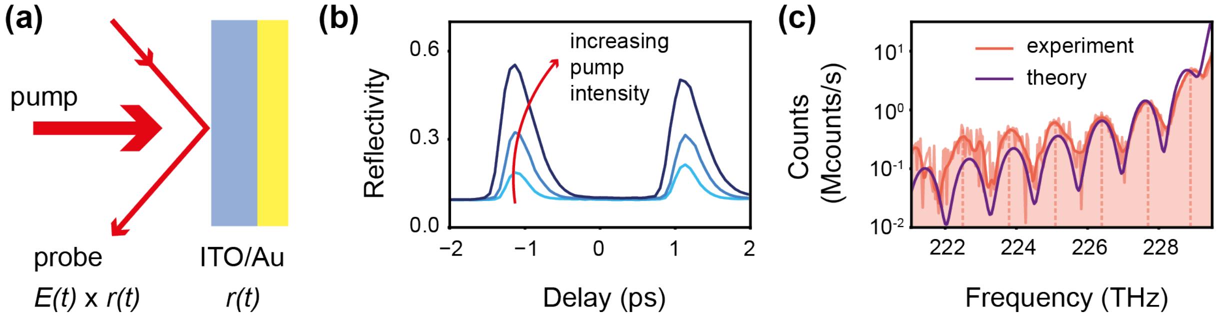


Figure 1: **(a)** Schematic of the pump probe experiment: a probe (thin arrow) is reflected by a time-varying mirror under pumping (thick arrow). **(b)** Change in reflectivity of the bilayer for increasing pump intensities at 230 THz under a double pump experiment, as a function of delay. **(c)** Resulting diffraction probe spectrum for a slit separation of 700 fs.

In a degenerate pump-prob experiment, a temporal modulation of the complex Fresnel reflection coefficient $r(t)$ is achieved under illumination by a pump pulse at 230 THz. As shown in Fig. 1(a), the probe pulse is then reflected bearing the mark of $r(t)$. Hence, changes in the reflection coefficient can be translated into new frequencies within the collected probe spectrum. We study a 40 nm thick ITO thin film on top of a gold mirror, and make use of the Berreman resonance to obtain a strong change in reflectivity within the pump pulse's width of 225 fs. As can be seen in Fig. 1(b) this change will be characterised by a fast rise, below the pump-probe's temporal resolution, and a slower decay of the order of 400 fs.

The reflected probe spectrum shows distinctive diffraction oscillations, shown in 1(c). The period of these oscillations is inversely proportional to the slit separation in time, as expected from Fourier theory. The oscillation amplitude decay, away from the main peak, is strongly dependent on the slit shape. Notably, the oscillations further away from the carrier frequency strongly depend on the slit's rise time, which cannot be determined with reflectance measurements only. By measuring the rate of decay of these oscillations, one can estimate a rise time of the order of 1-10 fs [3]. This is in agreement with previous results [4] and demonstrates the utility of time diffraction as a spectroscopic tool.

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[3] R. Tirole, S. Vezzoli, E. Galiffi, I. Robertson, D. Maurice, B. Tilmann, S. A. Maier, J. B. Pendry, and R. Sapienza, "Double-slit time diffraction at optical frequencies", Nat. Phys. (accepted), `10.48550/arXiv.2206.04362` (2022).

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